Wireless Avionics and Human Interfaces for Inflatable Spacecraft

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Abstract—Revolutionary capabilities for robust control of inflatable Lunar and Martian transit vehicles and planetary habitats can be developed using advanced wireless network technology and modular avionics coupled with facile human to system interfaces. Fully wireless modular avionics would eliminate any cabling associated with power and data transmission, allowing easy deployment of flexible control systems and human interfaces. Furthermore, wearable human interface systems hosting virtual reality interaction methods can provide significant improvement in human situational awareness and control of dynamic space systems. The crew can interact with intelligent software agents providing human-like interaction using speech. These advanced information management systems would incorporate intelligent software agents to assist the crew in performing vehicle and mission operations.

Advances in robust wireless data communications and wireless power transmission are the key technologies that enable this new spacecraft architecture. This paper will cover the proposed architecture for wireless spacecraft avionics including innovative human interaction techniques with spacecraft systems. The team believes these two aspects are intimately related and that mobile virtual human interfaces can solve many problems associated with operating spacecraft based on inflatable structures. Conventional architectures allocate much space to a cockpit from which the spacecraft is piloted and monitored. For the transit to Mars, which in most scenarios takes approximately 6 months, the cockpit becomes a major consumer of available space while being used only briefly during the journey for earth departure and planetary approach. Wireless control of the spacecraft would allow the piloting and monitoring function to be carried out from any location within the crew space. Identifying key technology developments required to support this architecture will involve evaluating current and next generation wireless networks, computational modules and wireless power transmission for avionics. Complementary methods for virtual human interfaces will be evaluated, with the rapid development of this technology enabling significant advances to be realized in the next decade.[1 2]

For piloting and monitoring functions it will be necessary to have virtual reality for looking outside the transit ship. Because of the radiation shielding required beyond the atmosphere and magnetosphere, there will be no clear view to the outside of the spacecraft. The visual capability will have to be provided by remote presence technology, which ties the virtual reality visual system with cameras on the outside of the craft. Spoken commanding and interaction with ship systems is also an important part of this concept. As ship systems become more complex, it will become impossible for the crew to remember exact details of all aspects of the operating environment. In this case the ability to ask questions about spacecraft status and have the agents issue audible spoken advisories and warnings becomes an important part of safely operating a very complex system. The shipboard agent systems can become in effect a much larger crew for the mission. With the round trip communication times approaching 40 minutes for the Mars transit, all of the mission operations knowledge will have to be built into the spacecraft, lessening dependence upon earth-based support. The operational authority has to be given to the astronauts augmented by virtual mission support provided by the knowledge agents on the spacecraft. A distributed wireless avionics system would provide the computational capacity for sophisticated support systems that inform the correct crewmember of a problem needing their attention, and to assist them in performing a complex task.

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1. INTRODUCTION

Inflatable spacecraft have advantages over conventional aluminum alloy spacecraft in launch mass and volume but pose unique challenges for spacecraft system design. Inflatable structures can be launched in a collapsed state, and then inflated upon deployment, providing a significant increase in usable volume. Moreover, these structures can be remarkably strong and resistant to micrometeorite damage if made from ultra-strong fabrics such as Kevlar. NASA has performed numerous design studies of such structures, notably the TransHab in 2000, identifying various challenges in design and solutions to problems such as deployment and system integration. This paper intends to present innovative design approaches to solving key challenges for inflatable structures, like flexible modular avionics, intelligent sensors and virtual human interfaces while defining innovative operations concepts for crew interactions with the vehicle and space environment during flight.

Commercial space ventures launched the Bigelow Genesis I Space Station "Hotel" in June of 2006 as a scaled-down flight demonstration.[1] It returned pictures of itself in Orbit as shown in the figure below. The level of interest in building and utilizing inflatable spacecraft can be readily seen from these investments and flight tests, but technical challenges remain. For example, the structure must be compactly stowed for launch, including the critical subsystems, which generally are not flexible in nature. All spacecraft need substantial wiring and plumbing for electrical power, air supply, cooling, command and control and providing this for a spacecraft that changes size is a major design challenge. Additionally, sensor and control signals and power connections must feed through from the exterior to the interior passing through several pressure interfaces while maintaining integrity during stowage, deployment and inflation.

This paper focuses on four key design approaches specific to inflatable spacecraft structures, but applicable to future spacecraft in general. The first one is to incorporate modular avionics nodes into the structure, using wireless power and data transmission for creating the integrated system. An important challenge is to remove significant wiring from the spacecraft by using inductive power transmission and wireless networks for command and telemetry signals. These methods also do not require penetration of the pressure interfaces. This has the added advantage of significantly lowering overall spacecraft mass, in addition to dramatically lowering the wiring complexity and its inherent impact on reliability. Methods of utilizing redundant wireless power and data transmission systems are outlined to ensure that these systems do not compromise overall vehicle safety.

Inflatable structures also require innovative methods of monitoring the integrity of the pressure shells and other components unique to this type of spacecraft. This is also true of the normal sensing required for environmental control and other vital functions. Intelligent modular sensors for pressure shell monitoring are introduced and methods for integration into spacecraft health management systems are outlined. Intelligent sensors also nicely complement the proposed modular avionics architecture thereby addressing the second design challenge.

Miniaturization and corresponding power reduction in electronic sensors and effectors now makes possible radical redesign of crewed spacecraft. These new designs promise significant reductions in power requirements and waste heat. Because the new sensors and effectors can communicate over wireless LANs and pull most of their power by induction from electromagnetic fields, a spacecraft designed around such hardware can use widely distributed architecture with the elimination of much of the connecting wires used for communication and power distribution. Indeed, the technologies for these functions can be imbedded almost arbitrarily throughout the spacecraft.

The third design challenge is the difficulty of creating windows and other means for monitoring the outside of the spacecraft. Since an airlock is required for human ingress and egress, the costs and reliability impact of this interior-exterior interface must be borne, but the same argument is not really true for windows. Windows are a problem for conventional spacecraft also, incurring significant cost and having an unfavorable reliability impact. Additionally, the need for substantial radiation shielding also creates issues with windows and other openings. Finally, each of these approaches penetrates pressure barriers, compromising reliability. Fortunately, modern computer technology has provided virtual means for such necessary functions that can potentially perform even better than conventional methods for providing situational awareness. Additionally, since this basic capability is needed for situational awareness, such virtual methods can be extended to command and control of the spacecraft. This paper will outline innovative methods for wearable virtual presence cockpit concepts capable of replacing conventional methods of spacecraft control and monitoring.

Innovative human to spacecraft system interfaces (HSI) require devices such as head-mounted displays and speakers for synthesized speech output and input devices such as cameras for pictures and microphones for speech. Information fusion, in the form of overlays of digital images with composite video and still images can present complex situations in a format better suited for human understanding. These methods are collectively known as "augmented reality". A more difficult challenge would be the development of algorithms to interpret actions and data input into commands from the crew.

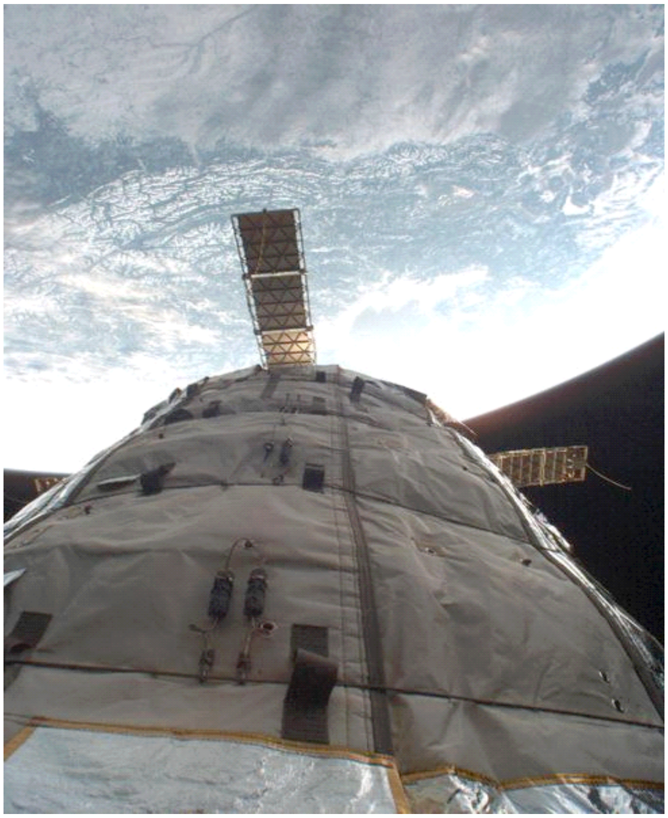

Figure 1. Bigelow Genesis I

Providing accurate situational awareness to the crew including spacecraft health and operational status can be extended to support missions operations such as Extra-Vehicular Activity (EVA) and robotic teleoperations. For example, would it be effective for a crewmember in the spacecraft to have the ability to "see" what and astronaut is seeing and doing during a spacecraft or planetary EVA? Operations concepts for such virtual HSI methods will be developed and presented, resulting in more flexibility and effectiveness for the crew aboard the transit vehicle or living in the habitat.

Devices alone do not solve the HSI problem. Better methods for interacting with critical systems are needed that significantly increase crew effectiveness and autonomy. Light speed delays and the impossibility of providing physical assistance to the remote crew make reliance upon an earth-based Mission Control Center (MCC) for dealing with time-critical system failures or mission contingencies a mode of the past. Intelligent software agents can be developed for crew-system interaction and for management of complex procedures, specifications and other tasks that need to be accurately completed in a limited amount of time, using the available resources. These concepts will be introduced in the context of virtual HSI devices and speech-based interaction methods.

It is anticipated that virtual HSI methods providing augmented reality are quite complementary to the modular avionics methods advocated for vehicle systems control and health management. Intelligent agents extend these capabilities by providing a "virtual person" for more natural human interaction. These methods require a facile, high-performance redundant distributed computing system with a low-latency network for data communication. In effect, the HSI devices become mobile nodes of the modular avionics system. The avionics system provides significant computational power for implementing virtual interfaces and intelligent agents. High levels of peer-to-peer redundancy and very high performance computing and communications capability, enabled by significant reductions of power, mass and volume of each avionics module can enable a remarkably flexible yet robust spacecraft command and control system, while providing the excess capability needed for crew and payload operations support.

2. Inflatable Spacecraft Design

Inflatable structures for spacecraft have been proposed and studied for many years. They provide significant advantages for space station habitats, transit vehicles and planetary habitats, particularly in terms of increasing usable volume for crew. Since they can be launched in a deflated configuration, with concurrent savings in mass, they provide a compact solution to delivering such spacecraft into earth orbit. Once in place, they can be inflated to provide a large habitable volume for crew transit or habitation. They can provide interesting structural advantages: the main support structure is isolated from the gas containment volume, while the gas pressure acts as a structural stiffener, with excellent shock absorption capability. Other advantages are the potential for better thermal insulation, micrometeorite protection and even radiation shielding, particularly when exotic multilayer materials are used.

Once at the intended site, they can be inflated, providing a significant increase in volume over rigid designs. The flexible fabrics used for inflatable spacecraft also can provide superior micrometeorite protection if constructed from materials such as Kevlar (having greater impact resistance than aluminum alloy). Of course, these advantages come at the cost of increased complexity for the design of spacecraft subsystems, which now must function in a variety of configurations, deflated, partially inflated and fully inflated. The flexible fabric of the pressure vessel also needs increased health monitoring for leaks and weak spots.

Design challenges for inflatable spacecraft include providing the strength and load bearing capacity required for propulsion, providing the signal, power and fluid interfaces between the inner pressurized volume and the outer environment, providing windows and other ports, mounting equipment to inner and outer surfaces of the containment volume, the design of the multiple flexible fabric bladder and mitigating the hazards of the outer space environment. Another challenge is to design subsystems that can function in the three major stages and configurations: deflated, inflation and fully-deployed. Given the critical nature of gas pressure for holding the structure inflated, leak detection and mitigation is a primary concern.

Certain functions will be needed during all three stages for monitoring basic spacecraft health during transport, but prior to deployment. Deployment must be carefully managed to avoid damaging the layered fabric and finally, leaks and other problems with the pressure interfaces must be quickly detected and sealed before the spacecraft collapses. All these design challenges can benefit from innovative avionics architectures and human-system interfaces.

Figure 2. NASA TransHab

Integrated Vehicle Health Management (IVHM) of inflatable spacecraft has been studied and high-level requirements defined. The structural health and gas containment are critical. This is no different than conventional spacecraft, except for the dynamic nature of the inflatable structure, which makes monitoring much more difficult. For example, in a rigid structure, any leak will be detected by a decrease in cabin pressure. Inflatable structures, by contrast, may not exhibit this pressure loss, since the volume reduces in direct proportion to the loss of gas, maintaining a constant pressure initially. Leakage repair and prevention of leak propagation are other challenges, mostly in the realm of material science. Since the space environment is harsh, the containment material must be able to withstand the effects of atomic oxygen, radiation and sunlight, as well as large temperature differences. An intriguing solution is to use the gas containment layers as a storage location for water and/or liquid hydrogen or oxygen, which could help with radiation shielding, given their ability to absorb neutrons and other radiation species. If water is used, thermal control of the water would yield excellent thermal control for the interior volume.

A good reference design is presented in Figure 2. In 2000, NASA studied the TransHab concept for providing a habitat for the International Space Station.[2] It provided a central rigid core for subsystems, airlocks, transport corridors and attachments. The outer shell inflated, increasing useable volume by 100% when deployed. A multi-layered fabric consisting of Kevlar, Inconel and other materials was prototyped and methods for measuring the integrity of the fabric were developed. For propulsion or life support functions, the subsystems would be located in the central core of the spacecraft, which accommodates thrust forces and provides a rigid structure for pumps, plumbing etc. An intriguing idea is to store the consumable liquids within the fabric of the inflatable structure, eliminating storage tanks. While not providing the full range of advantages associated with inflatables, particularly increased volume, the design was capable of being qualified for human space missions.

3. Modular Avionics Architecture

A popular avionics architecture for critical flight control aboard current-design commercial aviation and proposed spacecraft is Integrated Modular Architecture (IMA), consisting of multiple powerful computer nodes interconnected using a high-performance time-deterministic network. The software architecture conforms to ARINC 653, which defines independent partitions for running application programs such as Guidance, Navigation and Control (GNC), Systems Health Monitoring (SHM) and other spacecraft functions concurrently.[3] A key feature is the capability of running independent application programs in alternative partitions separated in both memory space and time-critical resource utilization. Another advantage is that the network provides many virtual paths for effective data transfer, enabling new modes of interaction between avionics modules.

In IMA, diverse hardware computing nodes use the network to maintain connection to many sensors and effectors simultaneously, allowing any computing module access to either sensor data or to control interfaces for subsystems distributed throughout the vehicle. Together with ARINC 653, this hardware capability allows any computing node to run a subsystem independent from the current location of the executing application program. Highly redundant and flexible software architectures can be constructed in this manner, ranging from traditional triple-redundant control schemes to advanced peer-to-peer constructs. Some of these schemes have yet to be proven, but will provide certain advantages if the design challenges can be met. The physical characteristics of inflatable structures lend themselves well to diverse peer-to-peer constructs with highly dispersed avionics nodes.

However, this same dynamic characteristic of inflatable spacecraft makes it very difficult to run cabling for signal and power transfer throughout the vehicle. One solution is to not use any surface of the containment volume for subsystem mounting, but this approach limits the degree of volumetric advantage obtained, by requiring a much larger core. In many ways, the very large core of the TransHab is one reason this design does not provide much volumetric advantage. If equipment could be mounted on the containment surface, then a much larger spacecraft could be constructed around a smaller core. Additionally, external resources could be mounted to the outside of the containment volume, providing additional capability like many camera viewpoints, antennas, solar panels and other important assets, arrayed around the vehicle, providing coverage in all directions. All these schemes require small compact modules providing these functions, with interconnections capable of stretching or contracting with the spacecraft during deployment stages. Reconfiguration of the volume for different mission phases or purposes might also be possible using this approach.

The key to such flexibility is to eliminate any physical media associated with signal and power transmission, particularly for avionics. Luckily, wireless techniques are now available that have the potential of meeting the needs for advanced inflatable spacecraft. The basic requirements for reliable power and data transmission can be met using redundant networks and power systems, all wireless, perhaps using diverse techniques to guard against common-mode failure. Radio and optical data transmission are two diverse data transfer methods, and inductive methods coupled with solar power or microwave power transmission would be two potential power supply methods. A battery in each avionics module would guard against temporary disruptions in power transmission. Logical and physical redundancy methods can be used to guard against temporary disruptions in network operation. Another key challenge in network design is to ensure the timely delivery of sensor data and commands to the critical avionics computers.

In Modular Avionics Architecture (MAA), described in this paper, many computational modules form a highly-redundant mesh network of computational resources for acquiring sensor data, calculating flight control and subsystem control loops, and commanding the actuator assemblies. This provides the ability to define the configuration of these avionics modules dynamically, either as highly redundant controllers, or as multiple computer systems each providing a dedicated function, with a huge aggregate computational capability. Coupled with ARINC 653, critical control and operations support functions can also be run concurrently in any avionics module, significantly increasing capability for hosting complex software. The best solution is probably a hybrid of these two approaches: a set of modules provides critical command and control, while the remainder is used for payload and mission support functions. As critical avionics nodes, fail, the support nodes switch function, backfilling the architecture so that a certain number of processors are always used for critical control. Therefore, this type of system will see a gradual decrease of non-critical support functions, prior to any loss of critical function. When all avionics nodes are operational, there is a large amount of excess capacity for other functions like supporting virtual interfaces and intelligent agents. Certain modules may act as cold spares, coming on-line only after numerous failures of the primary modules.

A block diagram of Modular Avionics Architecture (MAA) suitable for inflatable spacecraft is shown in the figure below. This is a notional diagram, intended to show how such a system might be constructed and how it might be managed. For simplicity, only three computational clusters are shown, C1, C2 and C3, representing the minimum complement for critical control. An actually implementation would have dozens of these cluster, each with similar characteristics. Each cluster has a complement of sensors located in reasonable proximity to their primary computational module, a wireless data link for the sensors and a mesh wireless network for connecting each cluster to the others and to the subsystems being controlled.

Referring to the diagram, sensors belong to a cluster where the sensors, utilizing their own “sensor” wireless data links, connect to the avionics module nearest to their physical location. In this example, the sensors are chosen to represent a system for monitoring inflatable structural health. Accelerometers (A-2) measure vibrations and movement of the fabric, strain gauges (S-2, S2-2) measure forces on the fabric, while temperature (T-2) and pressure sensors (P-2) measure properties of the fabric and environment in the vicinity of the cluster. By properly distributing these clusters throughout the inner surface of the containment volume, the entire structure can be monitored. Each cluster can be labeled as a vehicle monitoring zone, to specify its location and coverage. If the sensors are inertial measurement units, star trackers, GPS units and other navigational sensors, then the clusters can be used for flight control. If they are pressure, temperature, oxygen concentration and humidity sensors, then the clusters can be used for environmental control. Many combinations are possible, yielding a wide range of potential design solutions.

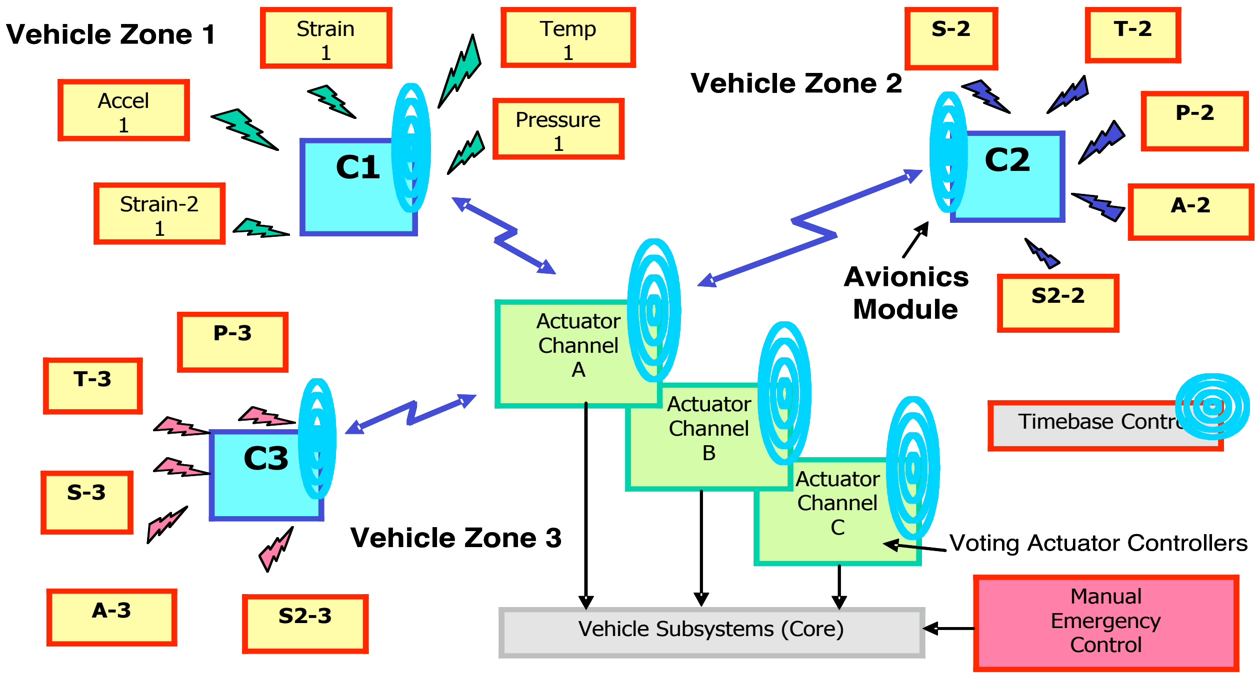

Figure 3. Modular Avionics Architecture

Certain avionics modules would be mounted on the exterior of the containment volume, outfitted with high-definition cameras for obtaining visual images and with interfaces for controlling solar power panels and radio systems mounted to the exterior of the spacecraft. They could be powered by the same inductive method that powers the interior modules and would be nodes on the mesh wireless network used for critical control.

A separate wireless "mesh" network connects the first avionics computing nodes (C1) to the other computing nodes (C2, C3). The mesh network creates a method for speedy propagation of all network data to all computing nodes and allows any of the avionics nodes to act as a communication repeater for any other node. The use of a mesh network provides routing capability from any node to any other node, even as nodes fail. Using this method, highly reliable interconnects can be created, even using unreliable means such as radio for the physical layer. The use of two diverse data transmission methods (i.e. radio and optical) improves reliability and prevents common-mode failures caused by electromagnetic interference or blockage of the optical path.

The computing takes place in multiple computing nodes that duplicate each others functions. Theoretically, with the same inputs, running the same algorithms, each node should produce the same results. The actuator control modules perform the majority voting scheme, rejecting any avionics nodes output that fails to conform to the others. In the event of failures, the sheer number of sensors and computing nodes ensure majority control, leading to a very robust system. The entire system is time synchronous, providing their control outputs to the actuator modules within the same time frame. The network must be capable of delivering all data and message traffic in the system within the time window required for time critical flight control functions, generally on the order of 10 milliseconds. A distributed, rather than central timebase is required for fault tolerance, and there are many such schemes.

Excess computational capacity is used to host a variety of crew and mission support applications, in particular embedded virtual/augmented reality HIS and intelligent agents for high-level interaction. Certain computational nodes can be human system interfaces, such as mobile displays with joysticks, virtual reality helmets and other unconventional devices. In microgravity, sitting down to a keyboard and display and using a mouse is not a valid concept. Astronauts generally Velcro the laptop to their knees and use their own body as the counter-weight for pressing keys and using trackballs or pointing pads or sticks. So, body worn computing is already used aboard spacecraft.

Sensors for Inflatable Structure Health Management

Intelligent sensors are another method for creating massively redundant spacecraft control systems, providing significant increases in monitoring capability and fault tolerance. The "intelligence" in this case is the ability to correlate multiple sensing elements and determine the correct average value, the ability to monitor internal sensing and measuring circuits and the ability to communicate on the wireless sensor network.

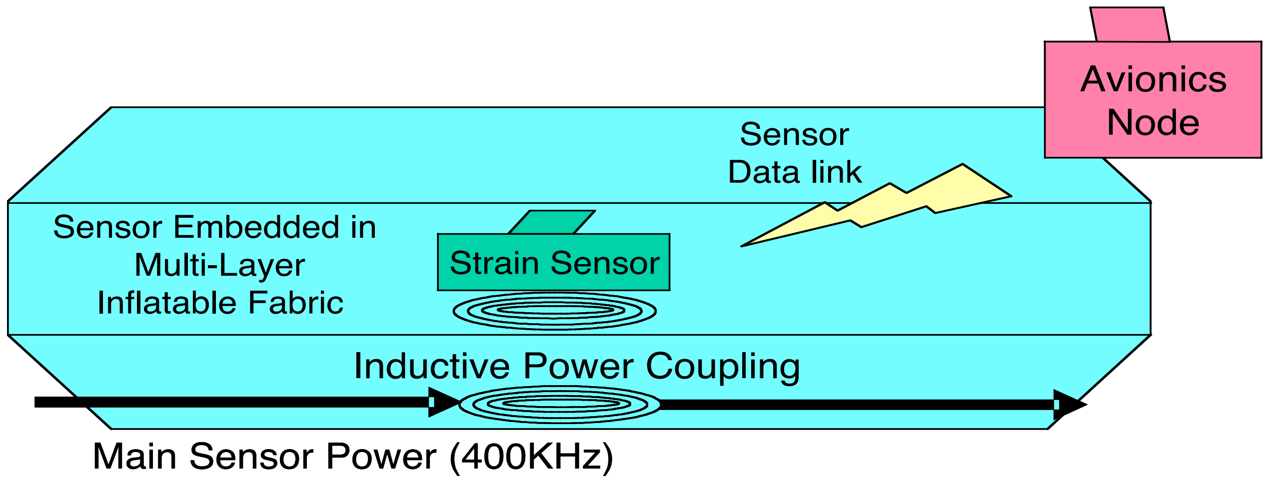

Figure 4. Embedded Intelligent Sensor

A key design challenge is to provide adequate sensing of the inflatable structure by monitoring strain forces on the fabric and detecting leaks. This would include environmental parameters such as temperature, oxygen and CO2 content and other key variables. One approach would be to embed such sensors into the fabric of the inflatable, in such a manner as to support the accurate measurement of the desired parameters. As in the case of the avionics nodes, these sensors would rely on wireless power and data transmission to function within the integrated system. Again, since the volume, mass, financial cost and interconnect cost of each sensor is minimized using this approach, one can afford to use many sensors. Highly redundant sensing systems allow many failures before reliability of the entire integrated system is compromised.

The diagram of Figure 4 shows how a strain sensor could be embedded into the spacecraft fabric, including the inductive power coupling and the associated data link to the avionics module. Channels for carrying high frequency current for powering the sensors and avionics modules would be created by conductive traces embedded in the fabric layers. These conductive traces could be associated with reinforcement materials to provide an integrated solution. Note that this solution requires no penetration of the critical pressure interfaces of the containment fabric.

The use of wireless data transmission eliminates any need for additional conductive traces, simplifying the design. Each sensor would need to interface to a wireless network dedicated to sensor modules, necessitating processing power co-located with the sensor to format the sensor data to the data link network protocol. If the sensor data stream were to be TCP/IP compliant, this would require significant processing power to implement due to the complexity of the Internet protocol. However, low-level peripheral interconnects such as Bluetooth or Zigbee networks could be used that only define the protocols to the data transport level, relying on low-level error handling. These protocols and physical implementations were designed with sensor networks as targets, simplifying the design of sensor networks, with much of the network protocol implemented in dedicated chips and low-power microcontrollers.

Data processing power available at the sensor location also allows implementation of intelligent sensor networks compliant with IEEE 1451.1, which defines smart sensor modules capable of facile networking in large-scale systems.[4] The corresponding Standard, IEEE 1451.2, describes Transducer Electronic Data Sheets for standardized information interchange of sensor data and characteristics, including calibration data.[5] The increased processing power can support sensors with multiple sensing elements, which allows cross-checking to be performed at the sensor module level, allowing more precise and reliable sensor design. Sensor failures are the number one most probable failure in aerospace systems, so improvement in this area provides significant advantages for vehicle reliability. [6]

There are many new types of sensors that can be used for monitoring the health of the inflatable structure itself. These range from microwave detectors for fabric integrity measurements, which detect impedance changes in the fabric indicative of changes in the multilayer dielectric constant to acoustic sensors that listen for leaks. Acoustic sensors, mounted to the surface of the inflatable could also pick up micrometeorite impacts, warning of potential damage. Fiber optics can be used, embedded in the fabric, with Bragg diffraction gratings used to monitor strain and temperature over a large area. Pressure sensors and regulators could be used to ensure accurate inflation and monitor the amount of make-up gas required to maintain inflation. These methods would detect very small leaks, but not their location. Interface areas between fabric to structure joints and other stress areas would need additional monitoring.

Fault Tolerance

The architecture can provide robust fault tolerance. In case of sensor failure, the architecture incorporates numerous redundant sensors for each critical function, always preserving multiple ways of performing the critical measurements. When all sensors are functioning, much redundant data is available for confirming sensor readings and calibration, covering sensor malfunctions or calibration drift. When fewer sensors are available, the algorithms can select the ones needed for closing control loops. Many sensors would need to fail in order to result in complete loss of function. This scheme requires many sensors and algorithms capable of determining consistency within sensor sets.

Similarly, highly-redundant wireless power and data interconnects provide reliability consistent with current wired systems. The key to implementing such highly parallel redundant systems is to reduce the cost of each sensor and computing package (volume, mass, power consumption and funding) to a minimum. Moreover, since each module is of the same design, significant effort must be applied for improving module reliability to prevent common-mode failures capable of affecting many modules simultaneously. Modern computing and sensor technology can allow such dramatic reductions in cost and improvement in reliability.

Applying dozens of computational modules to each critical control loop can provide a considerable excess of computing function in such a system, therefore loss of a computational module is simply a loss of redundancy. How many failures can be tolerated is determined by the excess capacity provided. Transient errors are covered by the voting and coordination schemes. Since much of the voting and coordination can be implemented in software and the hardware functions are relatively unconstrained, complex and novel methods for coherency can be employed. Many of these methods have yet to be developed and proven. Another key is the use of time stamping on ALL data and message traffic within the network, which minimizes the possibility of Byzantine fault modes in such highly parallel redundant systems. Data and messages that are not time synchronous with the current control cycle are rejected by the actuator controllers.

Redundant architectures need to cover failures of the actuators. Actuators can be control surfaces, thrusters, heaters, coolers, pumps, power switches or any other device that are needed for spacecraft flight control, life support and vehicle operations. Each actuator controller is a separate computing node, accepting control inputs from multiple computing modules and using a majority voting algorithm to accept only correct inputs. To prevent single-point of failure, these actuator modules would require redundant computing, data communications and actuator output functions. Again, the concept of double-fault tolerance would be applied to any flight-critical or crew-critical function. An important consideration is voting between redundant actuator modules. If a redundant actuator suffers an internal transient error, this is covered by requiring the three actuator modules to vote on each other's control outputs, ensuring that at least two of the three redundant channels agree on the next actuator state. This provides at least the same level of fault protection as current avionics designs.

Loss of the cockpit in an aircraft is critical, since there is only one of them. By incorporating diverse redundant HSI devices for flight control, this single point of failure is eliminated. Note how well the MAA supports roving HSI devices that support computational capability on the mesh WLAN. The MAA network routes the user input and output to the correct avionics module hosting the software being used. In case of HSI device failure, the crewmember uses an alternative or spare device.

Finally, incorporating simple backup flight control and critical control functions in the actuator modules, independent from the primary avionics, can provide disparate redundancy. Manual control interfaces for the crew can also be provided. However, this backup system would only possess rudimentary sensors and functions, sufficient to allow operation of critical subsystems for the duration of the primary control system outage. This is a low impact method for providing disparate redundancy to cover common-mode failures in the massively parallel primary avionics system.

4. HUMAN-SYSTEM INTERFACES

Virtual Human System Interface (HSI) devices can provide crew mobility, freedom from position constraints (common in earth gravity) or physical restraints (common in microgravity) through the use of body worn components, producing information fusion from a variety of spacecraft sources. Significant computational power is needed, particularly as user interaction modes become more complex through the use of intelligent virtual agents. Improvements in display technology are needed to allow high-resolution camera video and still images to be combined with computer status information. Methods of tracking crewmember position and orientation are needed to create the virtual fields, which change as the crewmember moves their head around. All this has to be provided in a comfortable manner, capable of being used for long-periods without fatigue.

Also, operator input also poses challenges for virtual cockpits and new methods of user input are needed, based on gestures and motion, or speech. Since the virtual cockpit may not have a specific dedicated location within the spacecraft, mobile methods are preferable. However, for critical operations such as docking, maneuvering and teleoperations, specialized devices such as trackballs or joysticks may be necessary. Devices that work using gestures, like the Nintendo WII computer game console, are potentially useful for this purpose. For interaction using speech, a headset would have to be worn. Finally, feedback to the crewmember, in the form of physical forces proportional to some desired parameter can provide a total immersion experience, leading to more accurate operation.

Speech and synthesized voice interaction is highly effective for general interaction with computing systems and research has significantly improved the capability for critical command and control. These systems use high-end phonetic speech recognition coupled with dialog managers designed for specific tasks. This combination significantly increases recognition accuracy and speed, providing pragmatic capability. For example, the crewmembers aboard the International Space Station (ISS) have tested voice recognition for use in critical procedure execution for checkout of space suits. [7]

Virtual Cockpits

Current spacecraft and aircraft have cockpits where all operator input and output is concentrated. Visual input from real images viewed through windows is used to fly the vehicle, with control inputs from sticks and hand-controllers directly affecting control surfaces. Additional flight systems information or autopilot headings can be shown in heads-up displays (HUD) or head-mounted displays (HMD) allowing the pilot to see both the view outside the cockpit and the ancillary information presented without changing his head position. Advances in fly-by-wire and other methods allow this direct connection to be bypassed in favor of computational methods that can provide significant advantages for control stability and robustness. Indeed, as in the case of the Supersonic Transport, cockpit windows were a real problem, and virtual methods of presenting external visual information to the pilot have been investigated. In this approach, cameras are used to present a virtual picture to the pilot, either using HUD or HMD technology.

Widely disseminated HSI hardware can match similarly dispersed MAA software architectures altering the need for spacecraft cockpits where information from all the vehicle's systems converges and from which it is controlled. HSI devices can be used at any location within the spacecraft, connecting to the nearest computing node using the wireless network, functioning well as roaming mobile devices, enabling innovative methods of HSI interaction for future spacecraft. Crewed spacecraft, in fact, can more and more be designed in the manner of remotely controlled vehicles in which the cockpit function does not need to be physically localized in one place in the vehicle and may even not be located within the vehicle at all.

The only time that cockpit functions are required is during transit orbit insertion, trajectory corrections and orbital insertion (assuming that the surface landings will be made in smaller craft). During this time the crew would don virtual reality (VR) headsets with microphones and earphones, and take out flight controls hardware, which might look like computer game controllers for the pilot and commander. All of the rest of the status checks and burn equipment readiness checks can be made by voice, and checking the virtual reality displays. Images from outside the spacecraft would be presented to the crewmembers, perhaps synchronized with the visual field, providing the capability for viewing the outside environment in all directions.

Crew location and tracking of body position are needed for taking advantage of these developments. Miniaturized low power sensors and effectors may be mounted on a variety of places on the crew themselves allowing precise tracking of their position, body postures, and biometric status, i.e. heart and metabolic rate. These parameters may be wirelessly transmitted to the relevant spacecraft systems allowing more accurate tracking of crew location and supporting maintenance of physical and cognitive workload within acceptable margins. Moreover, since these smaller head or body-mounted displays can move around with the user, they open the possibility of the virtual cockpit being totally mobile and accessible anywhere within the pressurized spacecraft volume. Indeed, if the wireless network is appropriately configured, the cockpit could even be accessed from outside the vehicle during EVA. (HAL9000 watch out!).

Augmented Reality

For ordinary vehicle and mission operations, the crew could use alternative displays and input methods, not requiring VR headsets. For example, the spacecraft could be equipped with beam forming microphone arrays and 3D spatial audio speakers, capable of monitoring spoken commands and providing directional audio output directly to the crewmember. This will allow the intelligent agent system to communicate with any crewmember and receive voice commands from any place in the spacecraft, including the crew quarters. Mobile hand-held displays or projected displays could provide a similar capability for visual information.

Each crewmember would have an area of responsibility and would be presented the appropriate displays, hand controllers and have the appropriate voice commands available. The software would implement a flexible presentation interface coupled to the workflow of the present operation, with crew being able to override the default presentation. At any point in time the system would be capable of answering questions, displaying diagrams and procedures and showing schedules and timelines.

Figure 5. Augmented Reality Concept Mockup

Functions for operating spacecraft systems and monitoring the progress of the mission can be done by augmented reality displays and voice commands. In augmented reality, information systems help crewmembers perform their duties by presenting relevant procedures in the correct time sequence along with relevant technical information, drawings and pictures. In effect, this type of assistant knows about the task being performed, using correlations to mission procedures and documentation to present the appropriate information to the crewmember at the right time, or upon request.

The augmented reality system will have at least the following capabilities:

(1) Controlling avionics and information displays.

(2) Reminding the crew of tasks to be performed.

(3) Alerting the crew to off nominal and emergency conditions in the spacecraft.

(4) Help running diagnostic tests and conducting recovery activities in the case of failures.

(5) Planning and scheduling crew work activities and communications.

(6) Navigation and mission progress reporting.

(7) Procedure execution assistance.

(8) Robot control and monitoring.

(9) Medical monitoring and diagnosis.

(10) Communication facilitation with Earth.

The spoken dialogue system will be the human interface to a series of intelligent agents which will help run the spacecraft both autonomously and under human control. These intelligent agents are software processes running in the computational modules, acting as high-level user interfaces to the control software. Because transit and habitat spacecraft will be more complicated than previous spacecraft, they will have to be largely autonomous for a small crew to operate and monitor, particularly for long-duration missions. Since speech is a very natural communication modality for humans, it will be the best interface to the spacecraft systems particularly when augmented by haptic pointing and gesture input devices and HMDs. Haptic devices such as miniature finger-mounted buzzers can also be introduced to provide positive tactile feedback for operation of virtual switches and knobs.

The key to coherent function is to virtually connect the HSI components to the software processes needing human input and monitoring. In the case of complex spacecraft, this usually encompasses multiple concurrent processes, with separate virtual displays for output. Training would be embedded in the system in the form of refresher videos for instruction. Overlays of information during repair operations can help guide the crewmember and provide procedures directly through displays or audio output, replacing paper methods. Most procedures have been migrated to electronic displays for ISS already. The picture in Figure 5 is a photo mockup showing flight engineer Vladimir N. Dezhurov using a virtual reality HMD aboard the International Space Station. Note the presence of copious amounts of paper procedures posted throughout the spacecraft, and the large amount of wiring, floating in the air, waiting to ensnare hapless crewmembers.

Since radio communication with the ground will be subject to long delays (about 40 minute light-speed round trip transit time), all the information necessary for problem solving has to be on board the spacecraft. Advanced search techniques will allow the crew to find the relevant documentation for any problem or sub-system in the spacecraft. The crewmember will be able to request information using spoken commands and flexible dialogue. The intelligent agent systems would be designed to try to diagnose problems and provide possible remedies because the spacecraft systems may be too complicated for crewmembers to understand in detail. Of course there will always be unforeseen problems, which will require human reasoning and diagnosis, which can be improved by the proper presentation of relevant information.

Virtual User Interface Design

The dramatic reorganization of crewed spacecraft made possible by the new computing and communication hardware and user-interface technologies requires appropriate design. Specific analyses need to be conducted to validate the savings and document the effect on the panoply of new risks and issues raised by adoption of virtual interfaces based on body worn sensors and displays. It is important to note that similar claims have been made about the underlying technology for decades, first when such body referenced computer displays were conceived in the 1960's and later when the aerospace applications were more specifically detailed in the mid 1980's. At those time the body position tracking systems, visual displays systems, interactive 3D computer rendering, and kinematic and dynamic computer simulations were not even approaching performance levels that would be practical. [8] These technical barriers have largely been broken and the principle remaining issues concern concepts of operations and system engineering. [9]

The virtualization of the user interface for cockpits and control centers raises a number of significant design issues because the very nature of such interfaces removes many of the sensory cues associated with conventional user-computer interaction, like the sound and feel of fingers hitting a keyboard and the kinesthetic position cues associated with mouse use. These ancillary cues are important for establishing control contexts and are very important to keep users aware of "where" they are in their task or software operation. Fortunately, the same display techniques that interfere with crew awareness can be used to enhance it by introducing naturalistic sensory feedback for inputs to virtual controls. For example, a switch closure on a visually presented virtual control panel can be confirmed by an auditory click as well as a visual change in color. If necessary, miniaturized tactile displays built into clothing or gloves can also be used to add haptic feedback.

The disseminated user-interface design should be guided by some of the rules for such systems proposed by Don Norman: [10]

(1) Be predictable.

(2) Keep things as simple as possible.

(3) Provide good conceptual models.

(4) Provide rich, complex, and natural signals.

(5) Make the output understandable, provide reasons for actions.

(6) Provide continual awareness, reassurance of intended operation without annoyance

(7) Exploit natural mappings of user input to environmental effects mappings

The first two rules incorporate a realization that unnecessary complexity in an interface is definitely a defect. Therefore, the system's expectation of user expertise needs to be indicated to the user to avoid affecting predictability. The remaining admonitions all relate to providing good conceptual cognitive models for system navigation. These support the predictability of the system since one of the features of a "good" conceptual model is that it leads to accurate expectations of system behavior. These accurate expectations are supported by the provision of rich, complex, natural feedback, recommendation four. This kind of feedback supports the understandability of the interface, recommendation five. The last recommendation to use natural mapping refers to metaphorical relationships between patterns of user inputs and systems responses and other analogous relationships in the real world. When we wish to modify something on our right, we typically move our hands towards our right. The guidelines outlined above must be made more concrete for specific designs, but their consideration will generally improve virtual user interfaces.

5. Intelligent Agents

A complementary concept to mobile virtual HSI for spacecraft command and control is the use of "intelligent agents" to act as avatars for human interaction, actors for autonomous operations and as experts for knowledge management. The large amount of computing provided by MAA aboard a spacecraft can be comparable to an Enterprise IT system. On a long duration mission to the moon or Mars, this capability may significantly improve the abilities of the limited crew complement to perform vehicle and mission operations activities and can lead the way to more autonomous, capable and reliable human spacecraft.

Figure 6. Spoken Dialogue Interaction

NASA Ames Research Center has developed prototypes for intelligent agents applied to mixed human-robotic teams and to planetary habitats. [11] These software systems were supported by facile mobile information systems and simulations of planetary surface surveys were conducted in analog environments. [12] The intelligent agents, implemented in the Belief-Desire-Intent language Brahms, responded to questions like, "Where am I?", "What is the current activity? What is the voltage from the generator?" and other queries of information available in the distributed IT system. The agents would also initiate commands to the robots: "Robot, take a picture of me" "Robot, go to location 1, GPS coordinates …" etc. Note how useful these types of human to agent interactions could be aboard a spacecraft and how they mimic natural interactions between people. Figure 6 shows a picture of an astronaut performing payload operations using interactive spoken dialogue interaction with a human on Earth. However, aboard a future transit vehicle, this may well be an intelligent agent, particularly when light speed delays prevent real-time communication with Earth.

Intelligent agents will be in effect the extra crew members needed to run and maintain the spacecraft. A crew of 3-5 persons may not be able to operate a complicated spacecraft without the support of virtual crew members capable of working 24/7. Many functions can be handled or augmented by these virtual assistants. Spacecraft monitoring, maintenance and repair operations are obvious candidates given the amount of work required on these tasks. Activities requiring specialized knowledge could be facilitated, such as medical treatment, by giving the human crewmember help in executing procedures for diagnosis and treatment. The following are brief summaries of selected agent functions proposed for particular activities.

Repair Agent

Intelligent agents can monitor subsystems and follow trends in operating parameters which might signal impending problems, and schedule maintenance before the system fails or loses significant function or performance. The following subsystems will need to be monitored continuously: 1) life support, 2) navigation, 3) propulsion, 4) communication, 5) consumables, 6) power, 7) radiation shielding, and 8) structural integrity. Most repairs have complicated diagnostic and replacement procedures to be followed along with needed diagrams and technical information. The spoken dialogue system can read out the procedure steps one by one and provide the necessary diagrams and pictures. All of this material needs to be on the spacecraft, so that no interaction with the ground is necessary to proceed with the repair. A set of intelligent repair agents can significantly reduce the time to diagnose and complete a repair while improving the quality of the repair.

Medical Agent

The crew is a vital part of the spacecraft and their health is as important to the success of the mission as the health of the vehicle. The health of the crew will be monitored continuously both during exercise and normal activities. This monitoring will have to be unobtrusive because of the long duration of the mission and this requirement is nicely met using body-worn sensors. Sensor-bearing vests or shirts have been suggested as ways of measuring heart rate, body temperature, EKG and arterial oxygen. These could be integrated with the sensors used to monitor location and body position for virtual HSI. These sensors provide information wirelessly to the spacecraft medical intelligent agent. The agents would keep track of all of the crew physiological data and analyze it for signs of medical problems in each crew member before they became serious. Often trends in medical data are very valuable for finding conditions that may become serious in the future.

During medical emergencies like injuries or breathing difficulties, the medical agent would interact with the care giving crew member to assist in diagnosis and treatment. Much work has been done in the past to develop diagnostic decision trees which allow the system and caregiver to make a rapid diagnosis. Since the medical agent would already have many of the vital signs, it could quickly eliminate diagnosis sub trees that do not match the measured symptoms. The agent could also communicate with earth-based flight surgeons for consultation, saving time during serious medical conditions.

Crew Personal Agent

Each crew member would have an intelligent agent to keep track of schedules, exercise, entertainment and correspondence with the earth. On the long trip to Mars it will be necessary to keep up a rigorous exercise program. Since the whole crew will be dependent on a limited number of exercise machines, it will be necessary to schedule these machines between the whole crew. The agent system will dynamically allocate exercise times and update the schedule in case of breakdowns and other delays. Scheduling and coordination can be optimized and the results of this optimization sent to the Crew Personal Agent for execution, by guiding the crewmember through scheduled activities. This same concept can be applied to any constrained resources.

Communication with the ground will be delayed for up to 40 minutes, so a system which keeps track of crew questions and answers received from Mission Control will be very important. When the answer to a question arrives 2 days after the initial query, it will necessary to pair the query and answer automatically to save crew time and jog their memory. These communications will be in speech and text/picture form and will have to be indexed and tracked.

6. TECHNOLOGY DEVELOPMENT

Implementing the MAA and associated HSI concepts will require investments in improving computer technology, both hardware and software. Fortunately, very little needs to be invented, since most components have either commercial or developmental predecessors.

Significant development of radiation-hardened avionics computing nodes would be needed. Power consumption would have to be dramatically reduced. Intelligent sensor modules would need to be developed, all minimizing installed cost. Sensor modules would need to be very small, incorporating multiple sensing elements, processor and network interface. The MAA relies on high-performance computing and networks, which can function at many times the rate needed for control. This large excess of performance is used for implementing the voting and coherency algorithms needed for effective coordination. Fortunately, modern semiconductor technology provides the means to implement all of these features.

In addition to further development of low-power radiation tolerant electronics, significant advances in avionics packaging would be required. For example, such avionics modules could not be liquid or conduction cooled, rather thermal control would have to be passive. Given the fact that no wired interfaces penetrate from the exterior, the use of completely sealed packages would be possible, which can increase reliability and interchangeability.

Network technology has progressed significantly with the adoption of AFDX time-deterministic Ethernet for critical aerospace control applications. [13] This is being used in the latest Airbus and Boeing passenger aircraft. Time-triggered Ethernet is a similar alternative. Each method relies on issuing packets on a timed basis, with sufficient gaps in between packets to allow other time-critical packets to be interleaved, which produces bounded latency. [14] Wireless network technology has similarly progressed, but to date, wireless time-deterministic networks have not been developed. Mesh routing software would be needed. Today, several products are available that perform mesh routing at either the MAC (Zigbee) or TCP/IP level (Tropos). Mobile IP routing has been flown aboard satellites in flight tests.

The biggest hurdle for implementation and biggest risk is the development of the necessary system management algorithms and software architectures needed for massively redundant peer-to-peer avionics systems. Although much of the critical control for MAA can be adapted from IMA, the larger number of possible redundancy solutions means that better means of maintaining coherency and failover would be needed. Model-based system management and diagnostics could be useful in this area. The system is reconfigured according to multiple constraints, synthesized from current system state. Planning algorithms could be used to determine the optimal process for reconfiguring such complex redundant systems.

Power transmission using inductive coupling is simply a matter of producing the correct magnetic interfaces. Semiconductor technology providing the high-frequency driving current is used in every switching power supply – not an issue for technology development. However, providing an alternative power source maybe more difficult, in that radiative schemes for power transmission may be difficult to apply internal to a spacecraft for humans. Triple-redundant power distribution schemes are possible, where each module couples with more than one distribution circuit. Again, low power electronics enables battery backup devices to be small and lowers the performance needed from wireless power transmission methods.

There are a number of building block technologies needed for the virtual disseminated interfaces we are proposing. The various sensory display devices that physically present the information to the users are a real challenge. These are devices such as miniature flat panel displays, and audio interfaces for head mounted systems. Recent advances in head mounted display technology benefiting from new OLED displays and redundant optical tracking systems make possible development of virtual cockpits based on body and head mounted displays that can present cockpit virtual images laid out within a user's 4π steradian field of regard. Such displays can replace the much heavier, power-hungry, flat panel displays of conventional control consoles with bright, high-resolution, full color, lightweight displays that only draw on the order of a few watts.

Other types of sensors such as miniature medical sensors currently exist and can be adapted to this use. Array microphones can focus upon the speech of a crew member in a given known location. The corresponding audio output function can be implemented using surround sound techniques, commonly used for home theater. Haptic sensors for interpreting motion and gestures are now available, but the feedback elements are lagging. Other types of user input devices are emerging, and may be useful.

The main challenge for HSI is not the device development, but rather the information and sensor fusion required for providing a coherent, yet dynamic and flexible user interface. The interface and display-rendering software that translates all the vehicle sensor and state readings into human sensory information and then encodes human voice and action responses into commands the spacecraft can use is particularly challenging. It is noteworthy that these translations may well be haptic and audible as well as visual.

A final building block for the disseminated user interface is the development of advanced packaging techniques for assembly of the HSI components into sufficiently small packages that may be unobtrusively introduced into crew quarters and crew clothing so that their use requires little or no special setup before operation. Power sources and lightweight batteries would be needed as well, compatible with the spacecraft environment. Changing your shirt may also change your batteries for the wearable sensors.

Intelligent agents are a focus for many of the activities of the Intelligent Systems Division at NASA Ames. Several demonstrations of early prototypes have been performed, so this area is considered one for development, rather than just research.

7. CONCLUSIONS

Inflatable spacecraft represent a revolutionary way of creating viable living and operations volume for humans engaged in exploration missions, providing increased usable volume with reduced launch mass and volume. They can potentially increase resistance to micrometeorite and space radiation hazards over conventional aluminum structures, while being more flexible for reconfiguration from transit to habitat modes. Challenges maintaining avionics operation during dynamic changes from stowed to deployed state during inflation, providing feedthroughs between the inner and outer surface of the pressure vessel, and for monitoring the health of the inflatable fabric itself can be met by applying innovations in the areas of avionics architecture, intelligent sensors, human-system interfaces and spacecraft information interaction, currently in the research and development phase. These innovations leverage the capabilities of each other to provide new concepts for the operation of long duration human spacecraft.

MAA is based on a massively redundant peer-to-peer construct, providing much higher fault tolerance and higher computational performance. Intelligent sensors have the potential for dramatically reducing sensor failures and inaccuracies, again by employing many redundant elements with internal cross-checking of function and accuracy. MAA directly supports roaming mobile HSI and its excess computational power can be used for hosting intelligent agent technology for information management and access. The use of wireless networks and wireless power distribution directly supports inflatable spacecraft by eliminating inflexible cables and feedthroughs across the pressure vessel.

An innovative operations concept for transit vehicle piloting, operation and maintenance was outlined, incorporating these technologies, providing virtual cockpits for vehicle operation, augmented reality for complex support activities and unobtrusive interfaces for common activities. Design guidelines for constructing such HSI systems were presented, consistent with current human factors practice. The use of intelligent agents nicely complements advanced HSI allowing natural interaction between crew and spacecraft systems and payloads, effectively increasing crew size.

Technology for implementing proof-of-concept prototypes already exists. Significant improvement in performance, power consumption, size, mass and cost are required for all elements, but are anticipated to be achieved using modern semiconductor advances. Packaging and hardening for the space environment will remain serious challenges.

Critical advances in software architecture and algorithms will be needed to integrate these widely dispersed assets into a coherent system, capable of maintain function despite failures and changing mission conditions. In many ways, the system architecture described is a good host for developing and testing many advanced software concepts. Agent-based design, in general, may help coordinate many of the loosely-coupled modules and functions identified.

Successful implementation of this architecture and complementary features can lead to more robust inflatable spacecraft, increasing the performance and capabilities of the spacecraft and its crew during the conduct of exploration missions to the moon and Mars.

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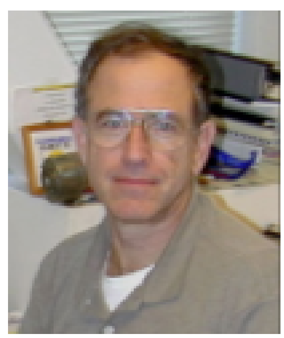
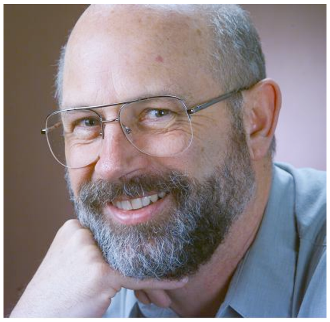
BIOGRAPHY

Richard L. Alena is a Computer Engineer in the Intelligent Systems Division at NASA Ames. Mr. Alena is currently working on the Mission Operations System for the LCROSS Lunar mission and on avionics architecture for a lander vehicle for human lunar missions. He was the co-lead for the Advanced Diagnostic Systems for International Space Station (ISS) Project, developing model-based diagnostic tools for space operations. He was the chief architect of a flight experiment conducted aboard Shuttle and Mir using laptop computers, personal digital assistants and servers in a wireless network for the ISS. He was also the technical lead for the Databus Analysis Tool for International Space Station on-orbit diagnosis. He was group lead for Intelligent Mobile Technologies, developing planetary exploration systems for field simulations. Mr. Alena holds an M.S. in Electrical Engineering and Computer Science from the University of California, Berkeley. He is the winner of the NASA Silver Snoopy Award in 2002, a NASA Group Achievement Award in 1998 for his work on the ISS Phase 1 Program Team and a Space Flight Awareness Award in 1997.



Stephen R. Ellis headed the Advanced Displays and Spatial perception Laboratory at the NASA Ames Research Center between September 1989 and March, 2006 and is currently a member of this group. He received a Ph.D. (1974) from McGill University in Psychology after receiving a A.B. in Behavioral Science from U.C. Berkeley. He has had postdoctoral fellowships in Physiological Optics at Brown University and at U.C. Berkeley. He has published on the topic of presentation and user interaction with spatial information in 170 journal publications and formal reports and has been in the forefront of the introduction of perspective and 3D displays into aerospace user interfaces. In particular he has worked recently on kinesthetic techniques to improve cursor and manipulator control under difficult display control coordinate mappings. He has served on the editorial boards of *Presence* and *Human Factors* and has edited a book, *Pictorial communication in virtual and real environments,* concerning the geometric and dynamics aspects of human interface to systems using spatial data.(Taylor and Francis, London. *2nd Ed.* 1993). He was awarded a University Medal from Kyushu Sangyo University in Japan in 1992.



Dougal Maclise is currently the group lead for the ISHM Technology Maturation Group within the Intelligent Systems Division at Ames Research Center. He has a Bachelors degree in Mechanical Engineering and a Masters degree in BioMedical Engineering. Over the fifteen years that he has worked at NASA, he has managed a wide variety of projects such as animal physiology experiment payloads for the Shuttle, the consolidation of seven resource tracking databases, a real-time imaging payload for the Solar-Powered Pathfinder UAV and the development of the Advanced Diagnostics and Prognostics Testbed. For the last five years he has focused on the systems engineering and application aspects of Integrated Systems Health Management while working on the Second Generation Reusable Launch Vehicle, Orbital Space Plane and Next Generation Launch Technology projects. He is currently the Information Systems lead for the Lunar Lander Project.

James Hieronymus is USRA Senior Scientist in the Collaborative and Assistive Systems (CAS) Technical Area within the Intelligent Systems Division at NASA Ames. He was technical lead for the NASA team which developed the Clarissa spoken dialogue system that talks astronauts through executing complex procedures which has been installed for testing on the International Space Station. He worked with John Dowding on the EVITA (EVA Intelligent Talking Assistants) spoken dialogue system for lunar space suits. The EVITA system forms a front end for the Mobile Agents system which keeps track of all of the assets on a lunar exploration mission, assists in scheduling, navigation, sample gathering and commands robots. His PhD is from Cornell University, masters degree from U Cal San Diego, and B.S. from the University of Michigan. He was a Post Doc at the Stanford AI Lab working on automatic speech recognition. He helped start the speech laboratory at NIST, was a linguistics professor at U. of Edinburgh in the Centre for Speech Technology Research, a Member of Technical Staff in the Linguistics and Spoken Dialogue Systems Departments at Bell Labs, Murray Hill, and a Visiting Professor at the University of Gothenburg. He joined NASA Ames in late 2000.